Where Some (or All) of Your Scientific Data Comes From

Satellites and Space Electronics

Image Source: NASA

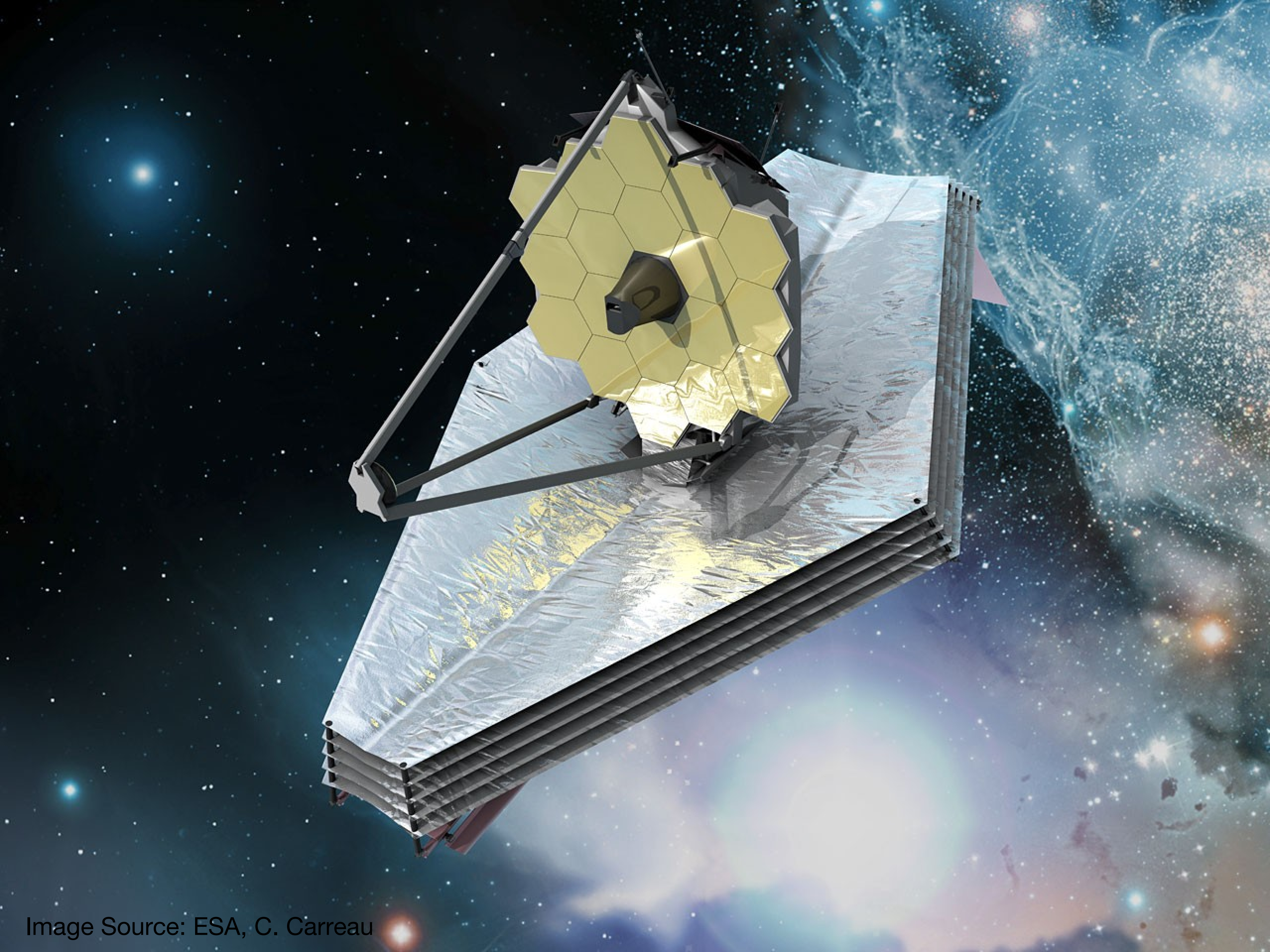
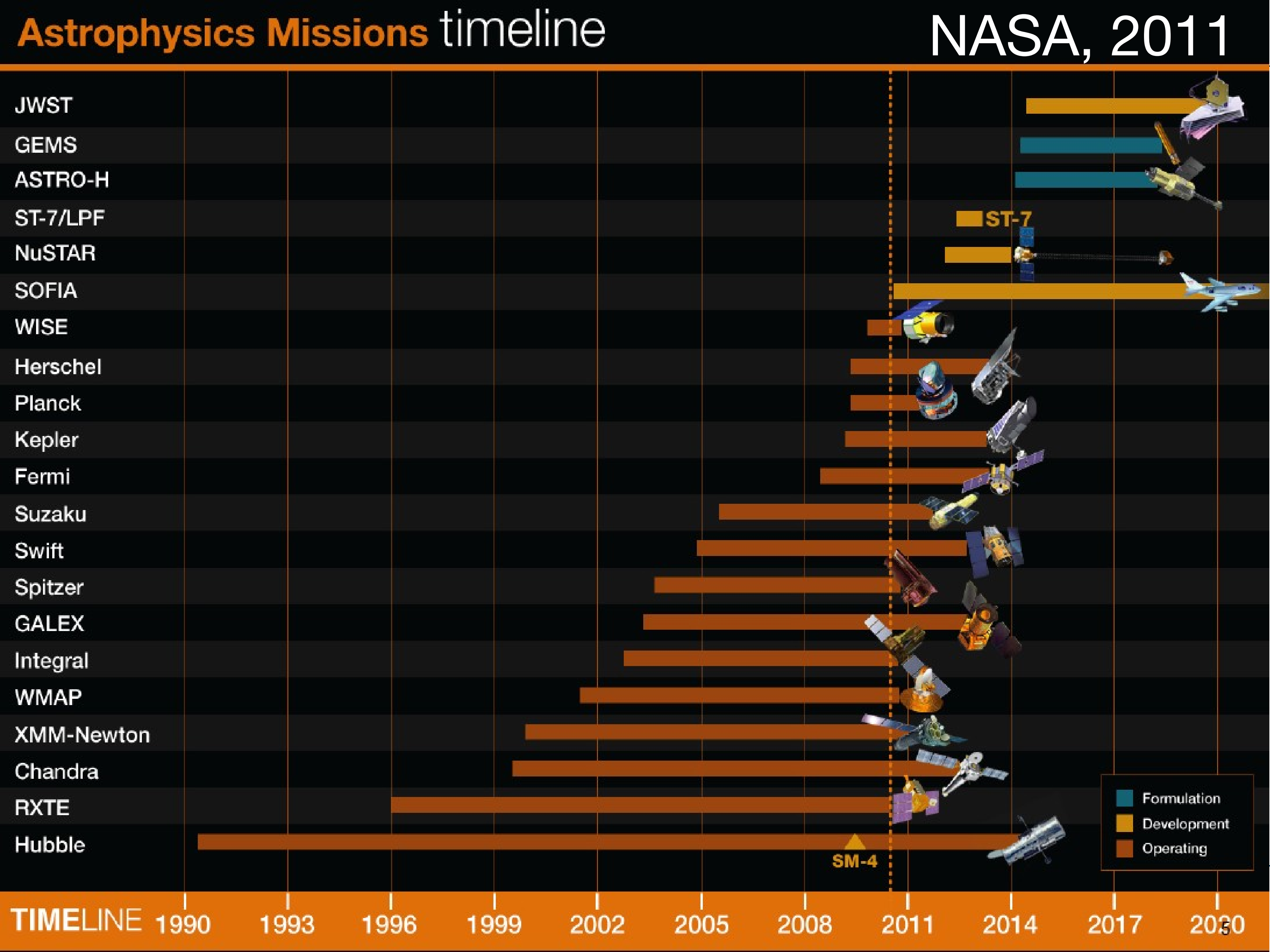
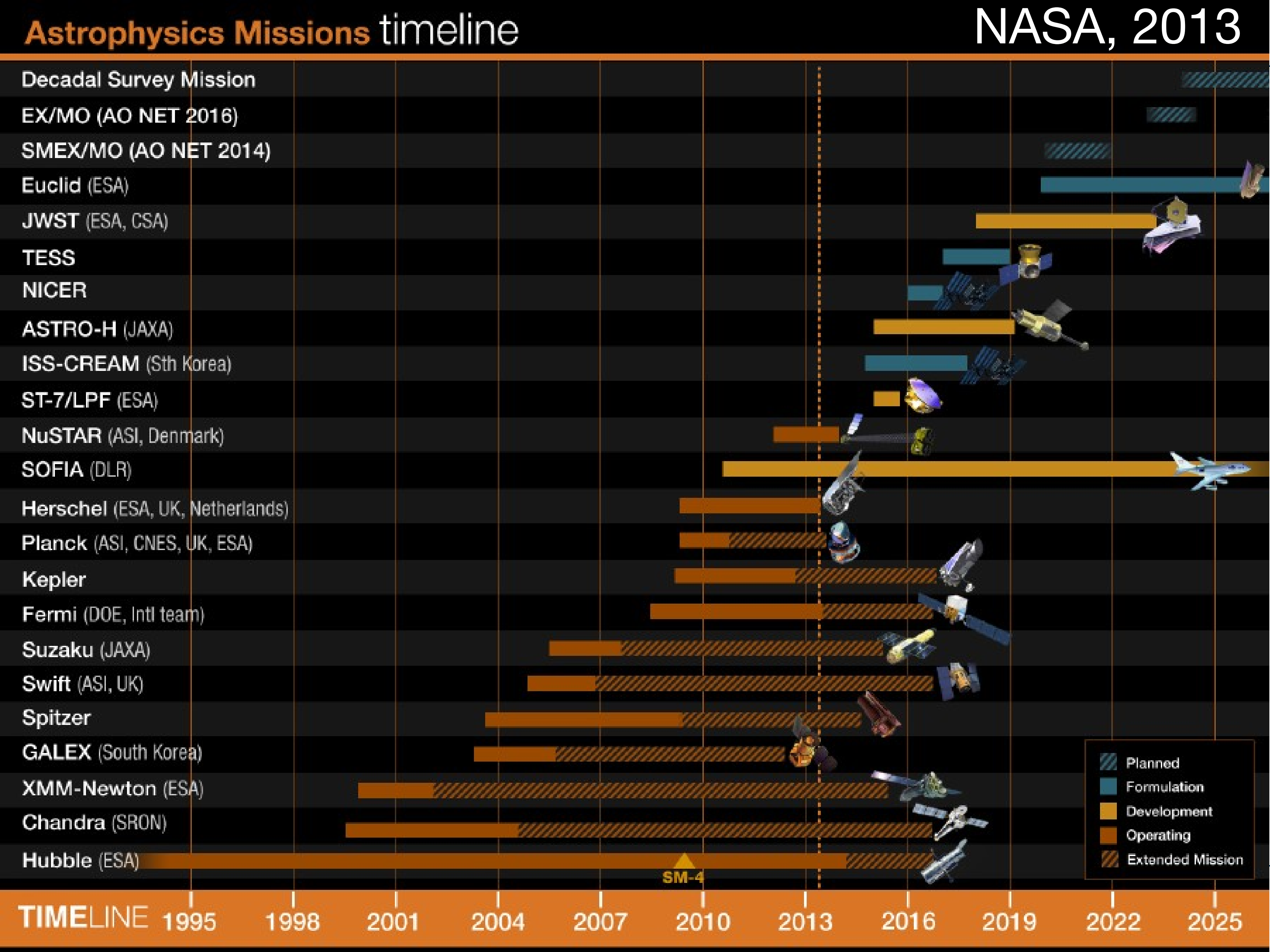


Image Source: ESA, C. Carreau



Astrophysics Missions timeline
NASA, 2011
JWST
GEMS
ASTRO-H
ST-7/LPF
ST-7
NuSTAR
SOFIA
WISE
Herschel
Planck
Kepler
Fermi
Suzaku
Swift
Spitzer
GALEX
Integral
WMAP
XMM-Newton
Chandra
RXTE
Hubble
SM-4
Formulation
Development
Operating
TIMELINE
1990
1993
1996
1999
2002
2005
2008
2011
2014
2017
2020

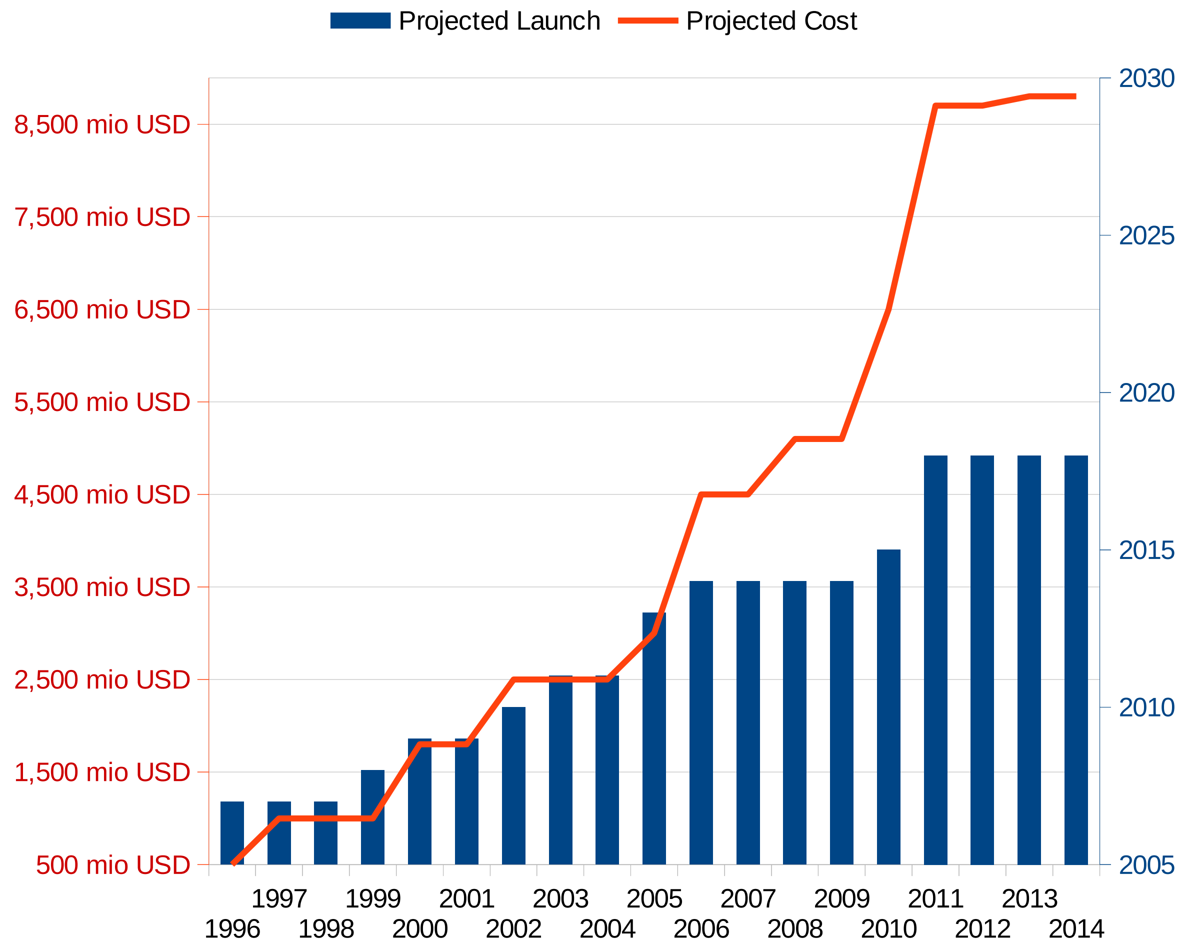


Astrophysics Missions timeline
NASA, 2013
Decadal Survey Mission
EX/MO (AO NET 2016)
SMEX/MO (AO NET 2014)
Euclid (ESA)
JWST (ESA, CSA)
TESS
NICER
ASTRO-H (JAXA)
ISS-CREAM (Sth Korea)
ST-7/LPF (ESA)
NuSTAR (ASI, Denmark)
SOFIA (DLR)
Herschel (ESA, UK, Netherlands)
Planck (ASI, CNES, UK, ESA)
Kepler
Fermi (DOE, Intl team)
Suzaku (JAXA)
Swift (ASI, UK)
Spitzer
GALEX (South Korea)
XMM-Newton (ESA)
Chandra (SRON)
Hubble (ESA)
SM-4
Planned
Formulation
Development
Operating
Extended Mission
TIMELINE
1995
1998
2001
2004
2007
2010
2013
2016
2019
2022
2025

Agency Spaceflight Progresses Slowly

- Why?
  - It's complicated!
  - Space hazards
  - Technological readiness
  - Export restrictions
  - Other legal issues
  - Politics (!!)

- Examples:
  - JWST 23y (maybe)
  - Hubble 20y
  - Spitzer 20y
  - Herschel 16y
  - XMM/Newton 14y!



Source: jwst.nasa.gov

Design Restrictions for Electronics in Space

- Technological Readiness
  (Agency & Commercial Spaceflight)
- Constrained power budget
- Form factor limitations
- Stress during launch
- Slim up- and downlink
- Operation in orbit

Image Source: ISC Kosmotras

Environmental Effects on Electronics in Space

- Extreme temperature changes
- No heat dissipation due to convection
- Radiation & single event effects
  - Total ionizing dose, event upsets
  - Latchup, displacement damage

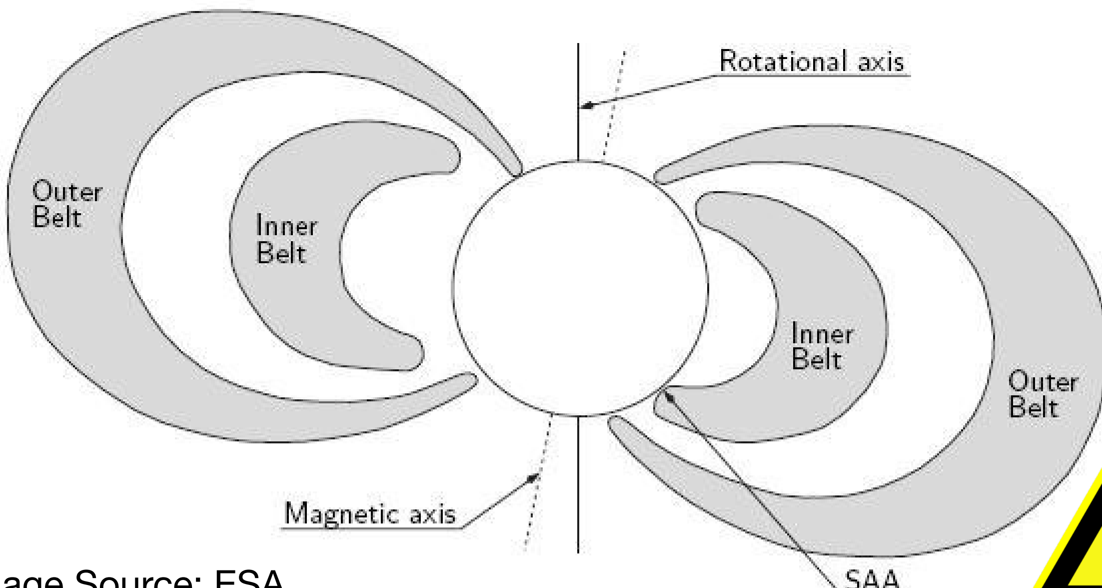


Image Source: ESA

Satellite Miniaturization

- Microsatellites
  - 10 - 100 kg
  - MUCH easier to develop
  - Have become very popular for commercial spaceflight
  - Still somewhat expensive (>_<)

- Pico & Nanosatellites
  - 0.1 - 10kg
  - Fast & easy to develop
  - Minimal launch costs
  - Many university projects
  - SCIENCE!

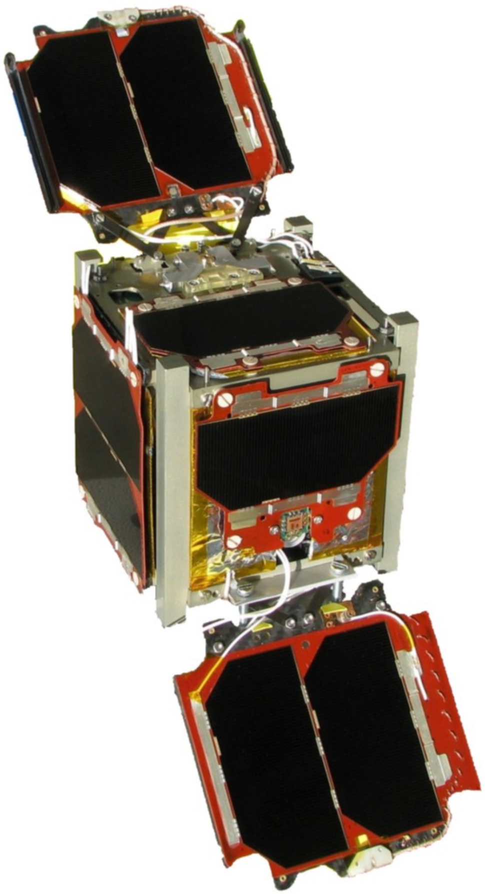
Image Source: NASA (t), Planet Labs (b)

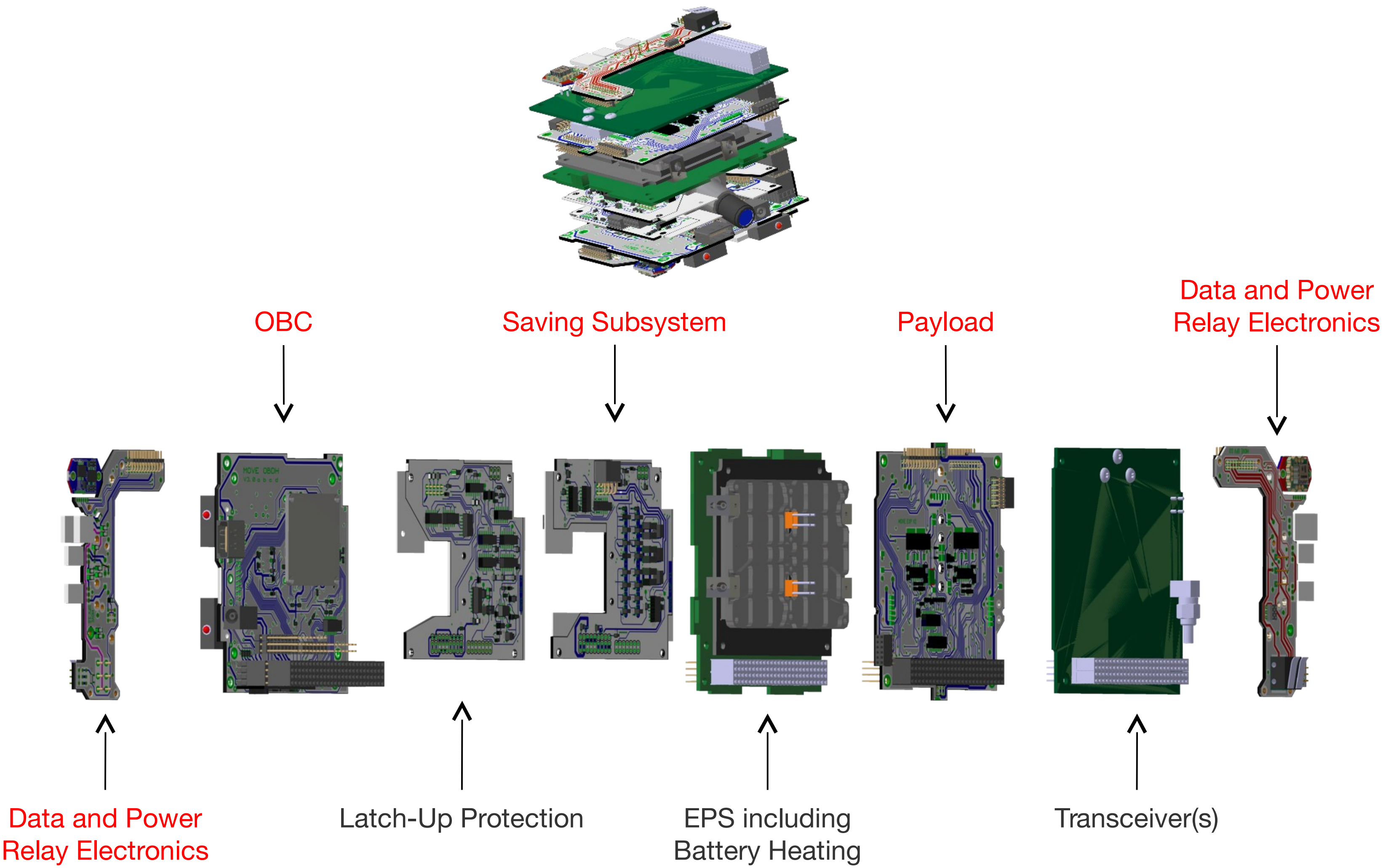
Nanosatellites - First-MOVE

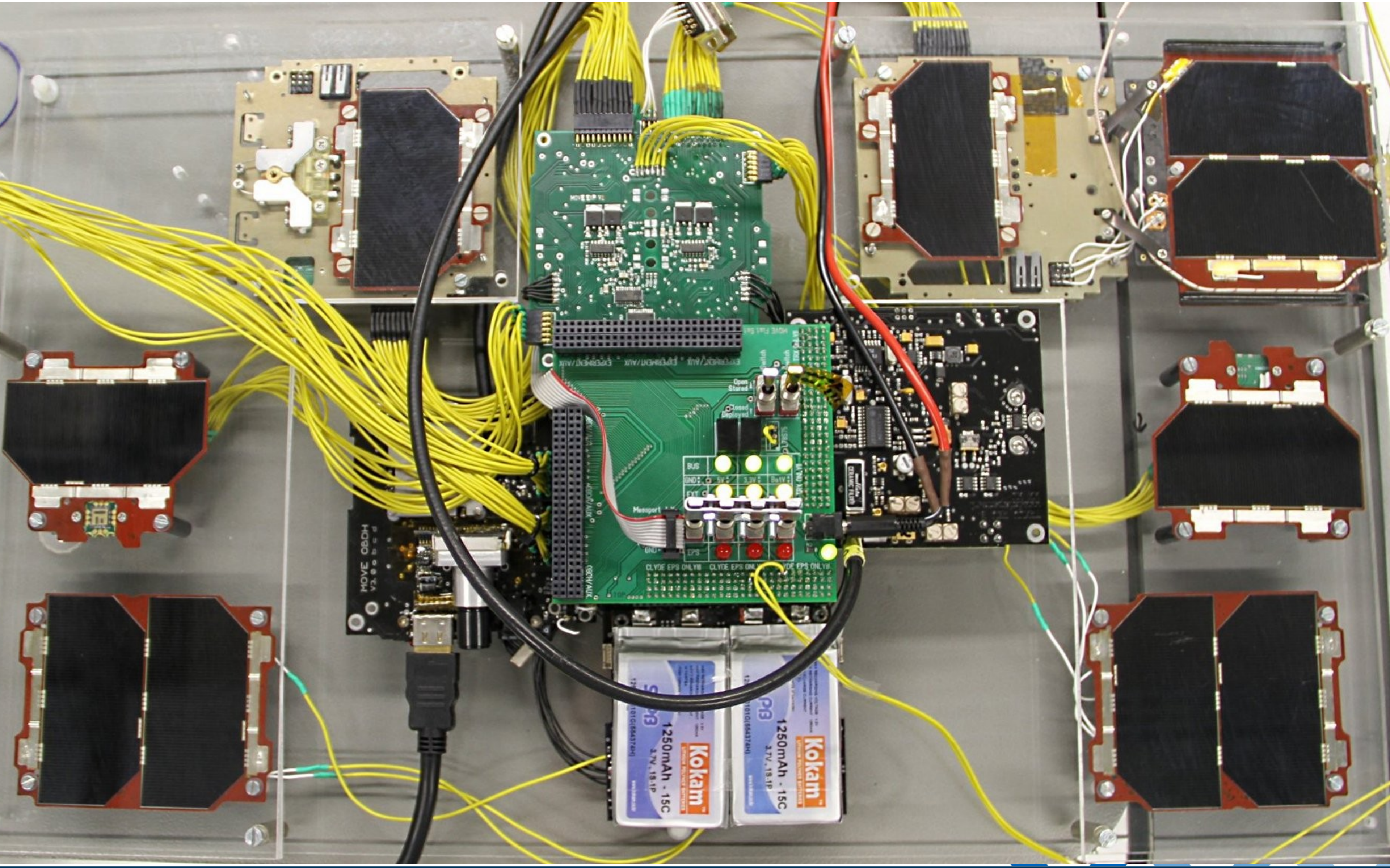
- “Completed” in 2011
- Launched in 2013
- 1 Unit CubeSat, 912g
- Technology demonstration

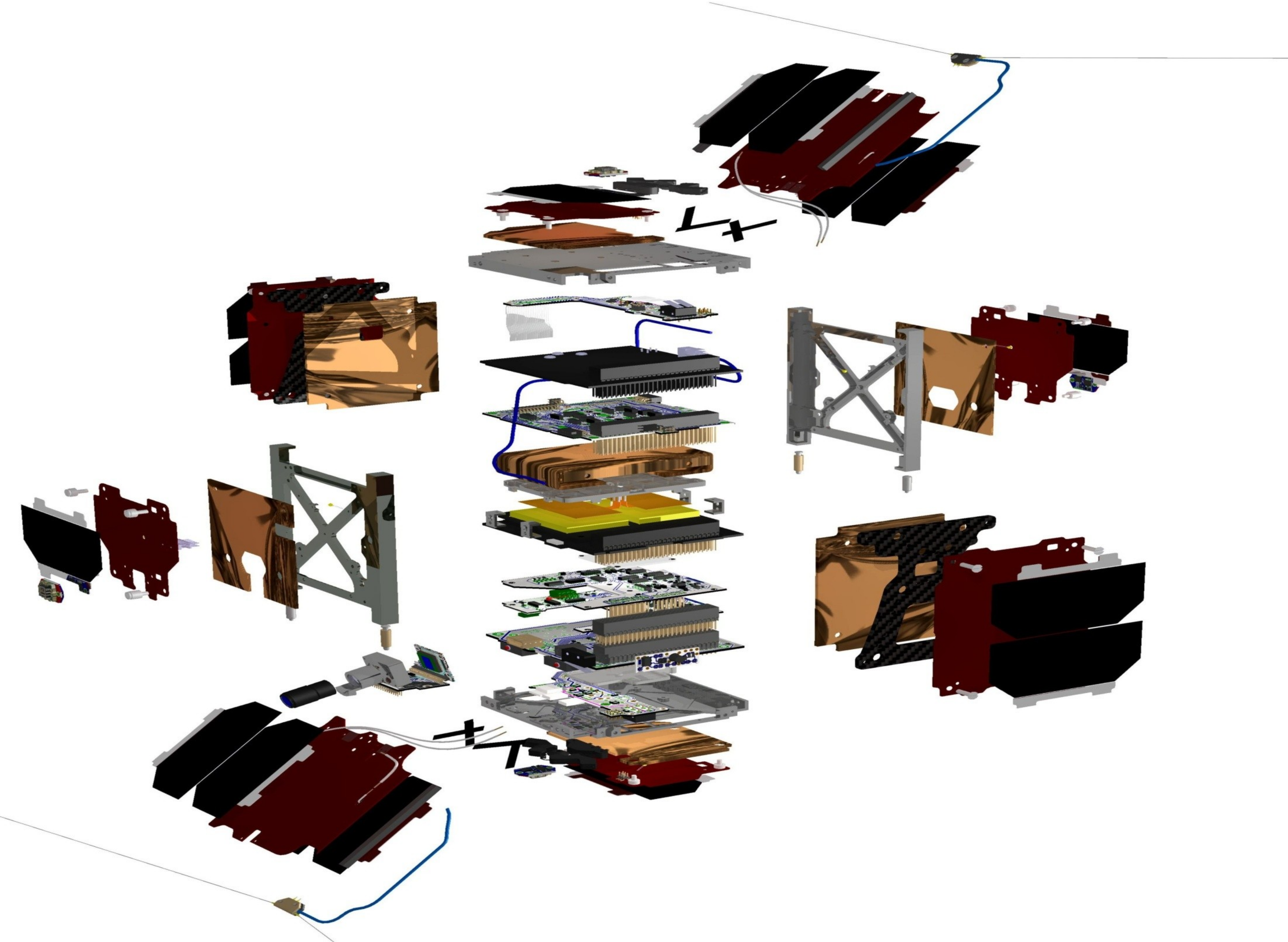
- UHF up- VHF downlink
- Foldable solar panels
- ARM926 based microprocessor
- 512KB MRAM
- 256MB Flash
- 200mW - 1.4W power consumption
- Custom OS

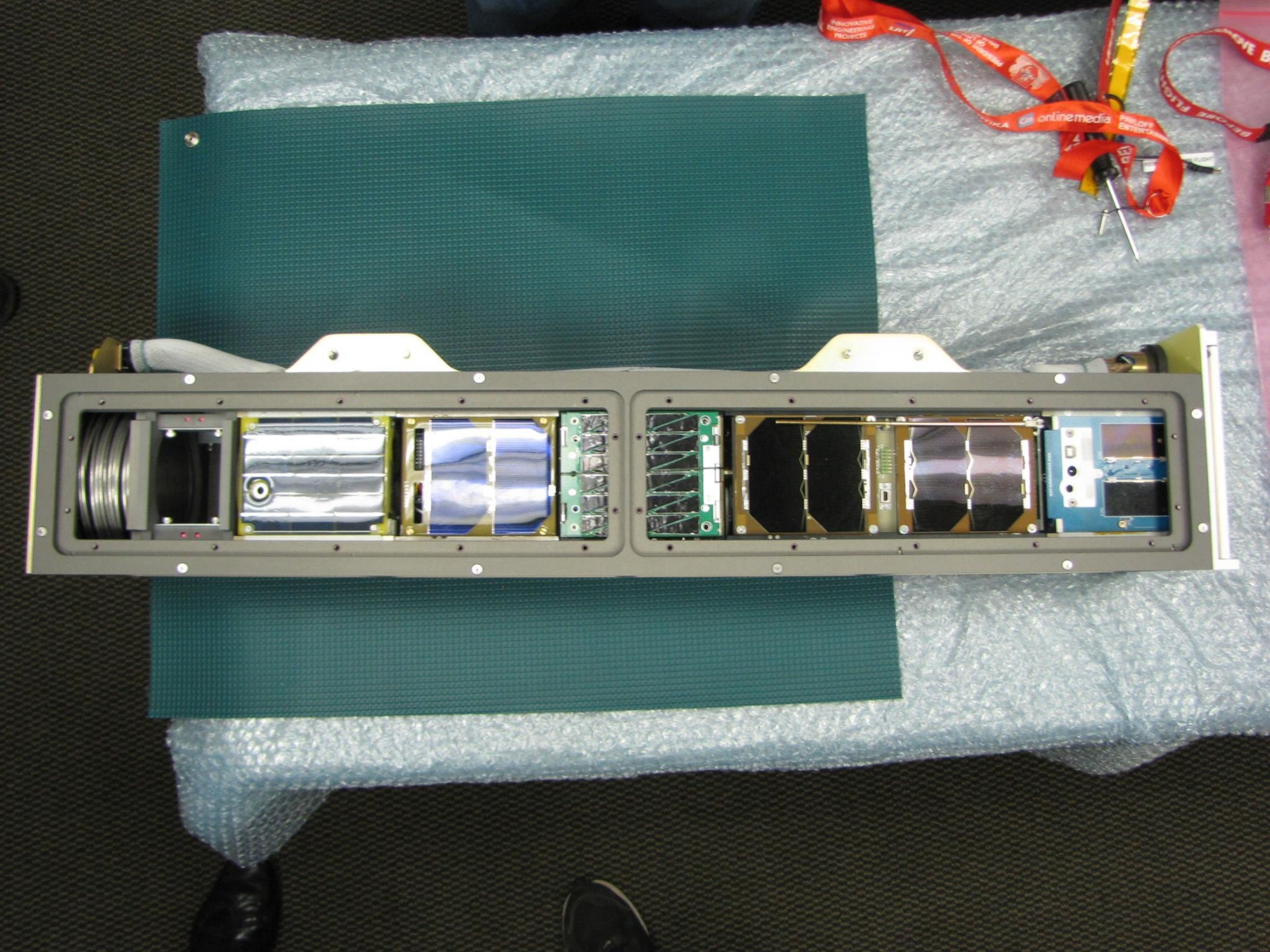
- Cost: ~200k USD/EUR incl. launch

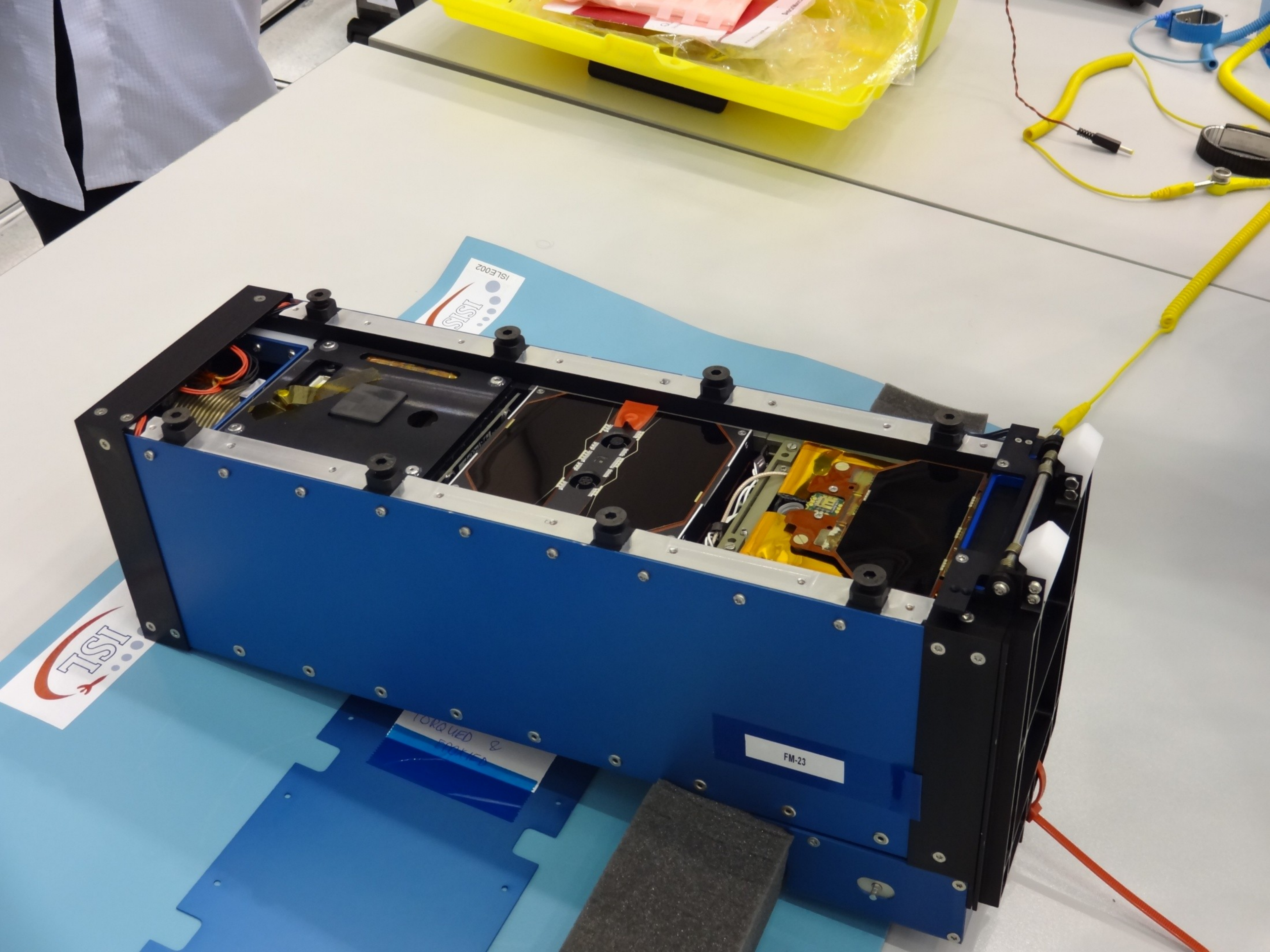


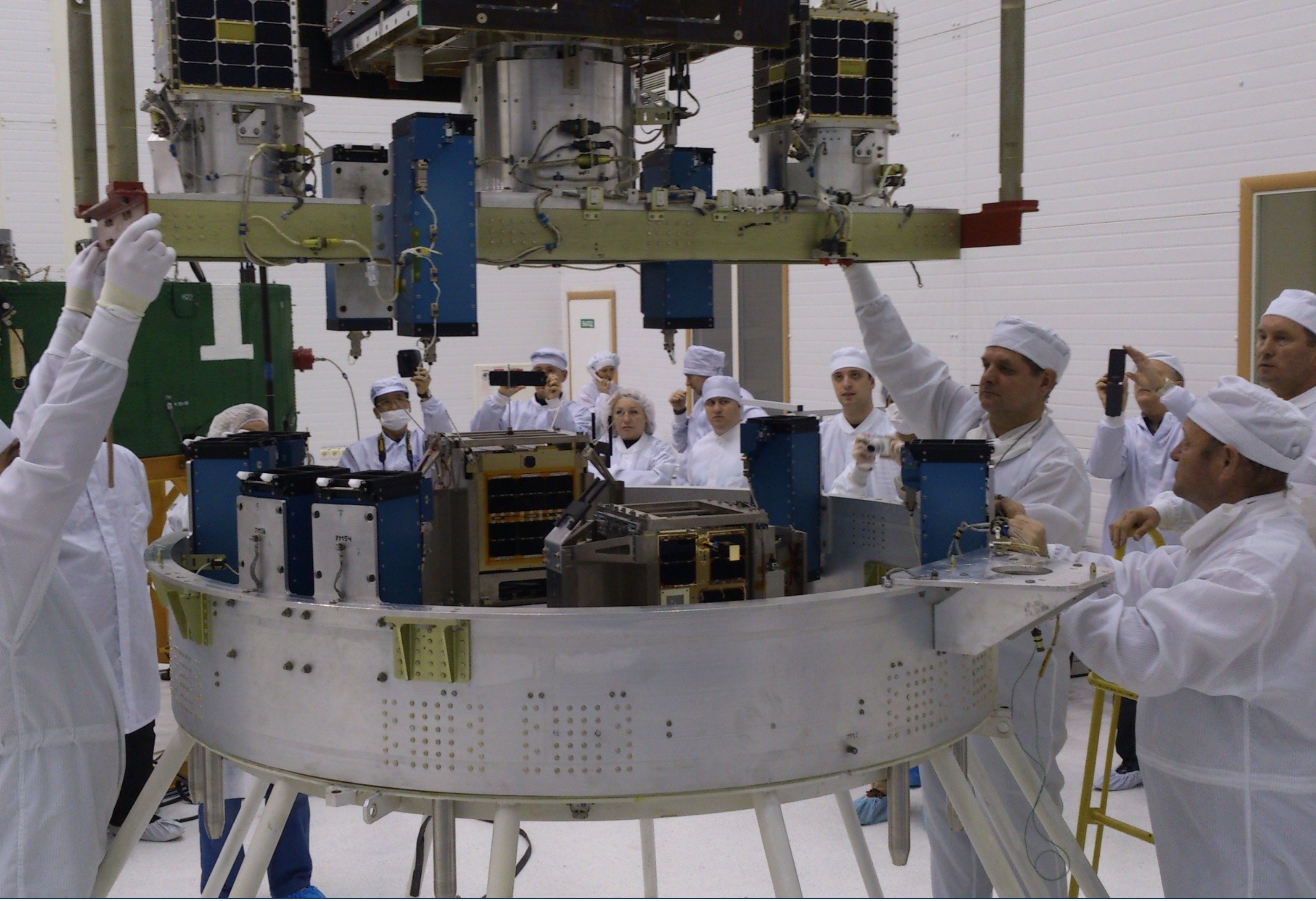

OBC
Saving Subsystem
Payload
Data and Power
Relay Electronics
Data and Power
Relay Electronics
Latch-Up Protection
EPS including
Battery Heating
Transceiver(s)


MOVE OBDH
Kokam
1250mAh · 15C
Kokam
1250mAh · 15C
CLYDE EPS ONLY!!!
CLYDE EPS ONLY!!!
CLYDE EPS ONLY!!!




INNOVATIVE ENGINEERING PROJECTS
online media

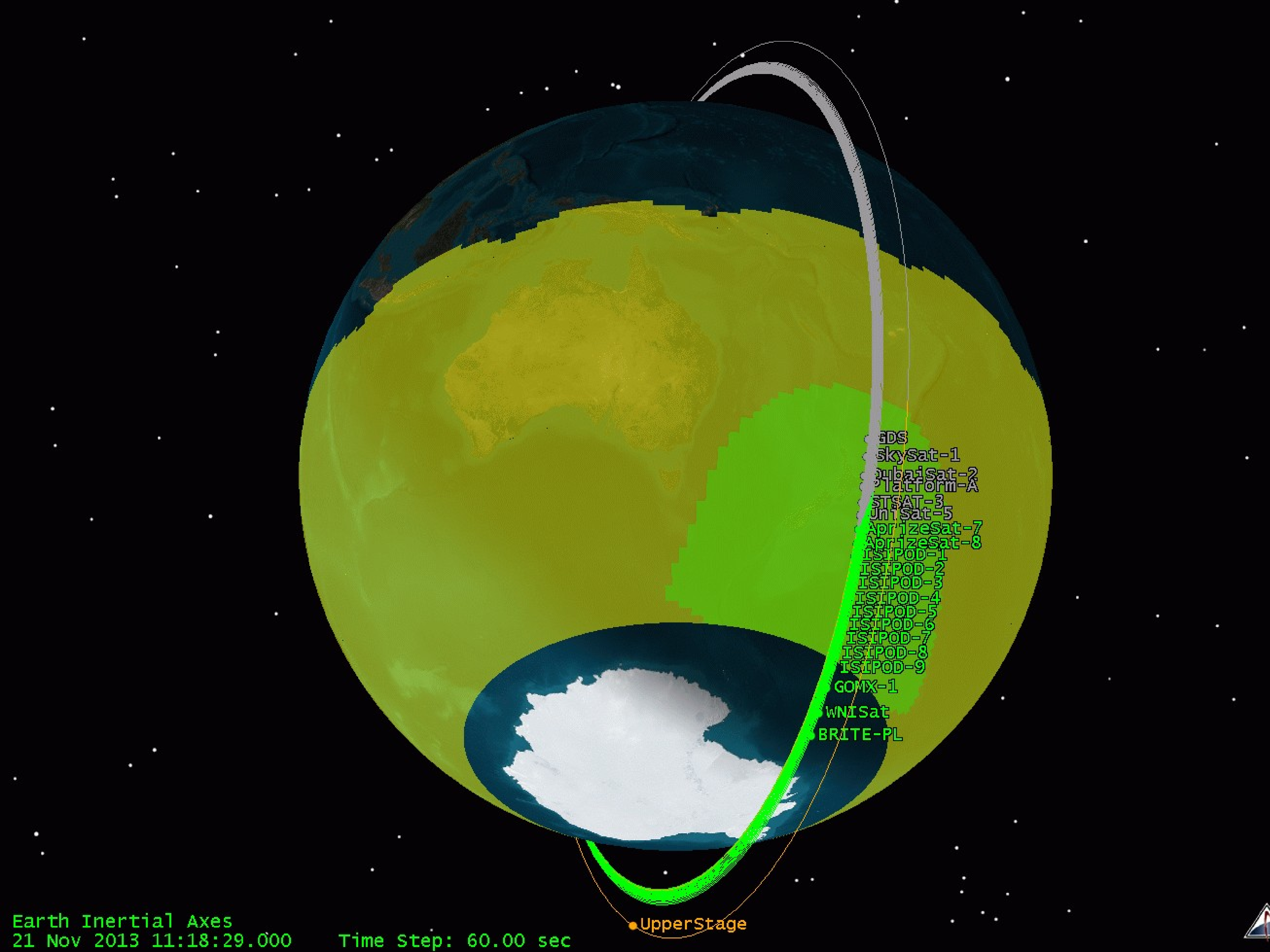

ISLE002
TORQUED &
FM-23

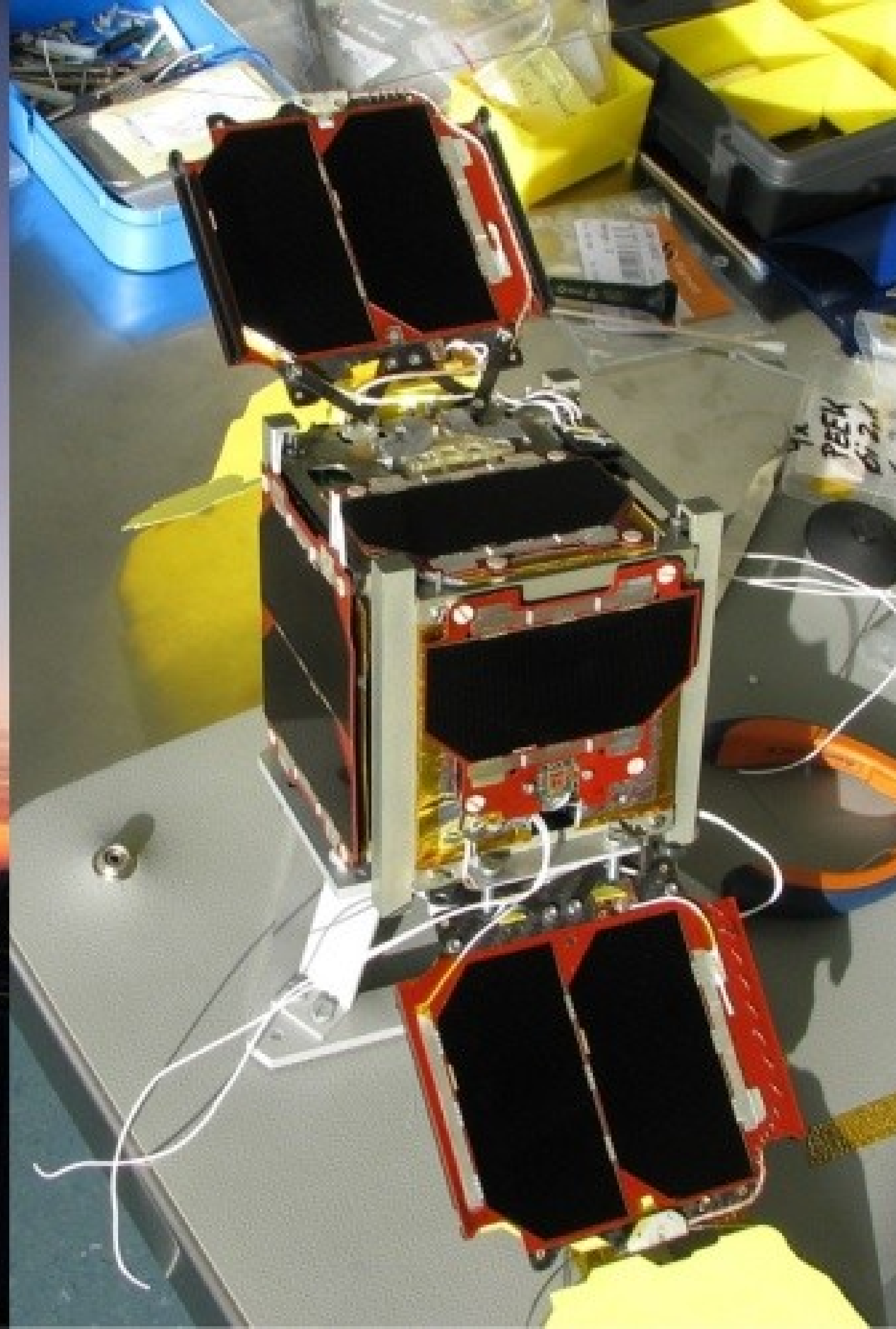


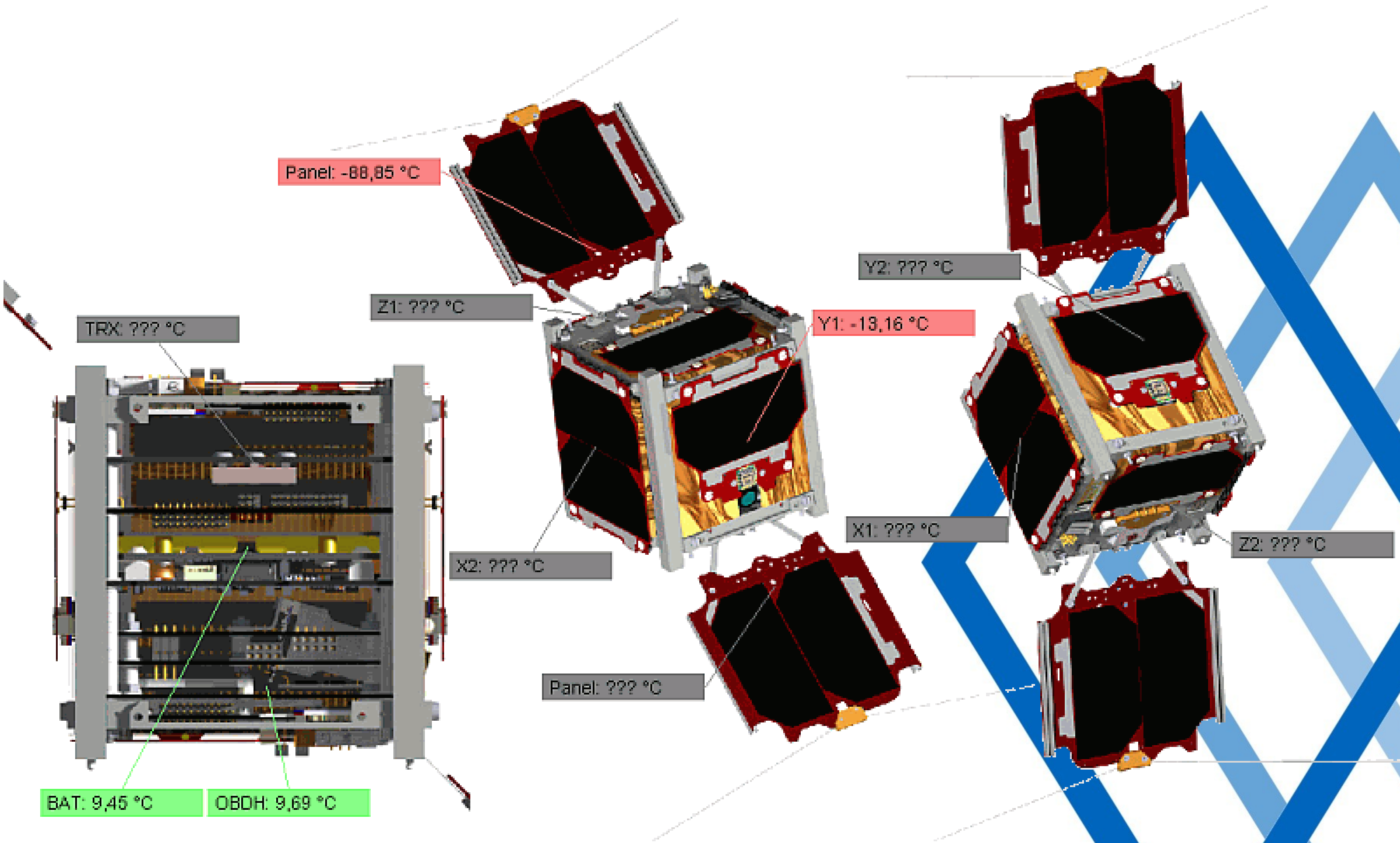

КОСМОТРАС
Днепр
KOSMOTRAS
ROSCOSMOS
YUZHNOYE
YUZHMASH
ҚАЗАҚСТАН ҒАРЫШ САПАРЫ
KazEOSat
SURREY
DEIMOS-2
elecnor
deimos
UniSat 6
SaudiSat-4
KACST
HODOYOSHI-3,4
ほどよし
3,4
東京大学
THE UNIVERSITY OF TOKYO
AprizeSat
9 &10
SPACEQUEST
TabletSat-Aurora
" ТаблетСат- Аврора "
SPUTNIX
СПУТНИКС
BRITE-Toronto
BRITE-Montreal
XPOD Systems
UTIAS
SFL
Space Flight Laboratory
BugSat-1
21 CubeSats
ISIS
ISL
QuadPack Systems

КОСМОТРАС
SkySat-1
14 CUBESATS


YUZHMASH
YUZHNOE
Днепр
esa


GDS
SkySat-1
DubaiSat-2
Platform-A
STSAT-3
UniSat-5
AprizeSat-7
AprizeSat-8
ISIPOD-1
ISIPOD-2
ISIPOD-3
ISIPOD-4
ISIPOD-5
ISIPOD-6
ISIPOD-7
ISIPOD-8
ISIPOD-9
GOMX-1
WNISat
BRITE-PL
UpperStage
Earth Inertial Axes
21 Nov 2013 11:18:29.000
Time Step: 60.00 sec



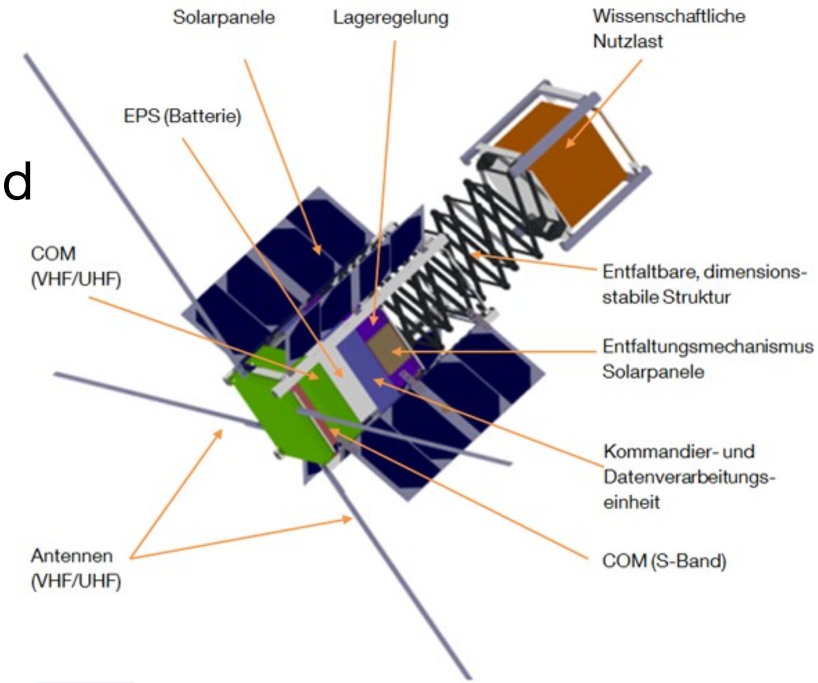

Panel: -88,85 °C
Z1: ??? °C
TRX: ??? °C
Y1: -13,16 °C
Y2: ??? °C
X1: ??? °C
Z2: ??? °C
X2: ??? °C
Panel: ??? °C
BAT: 9,45 °C
OBDH: 9,69 °C

MOVE-II System Concept

- 2U or 3U Cubesat
- 13W power budget (with 2U)
- 2W CDH power budget
- Size-optimized Linux based OS
- Communication via UHF/VHF + S-Band

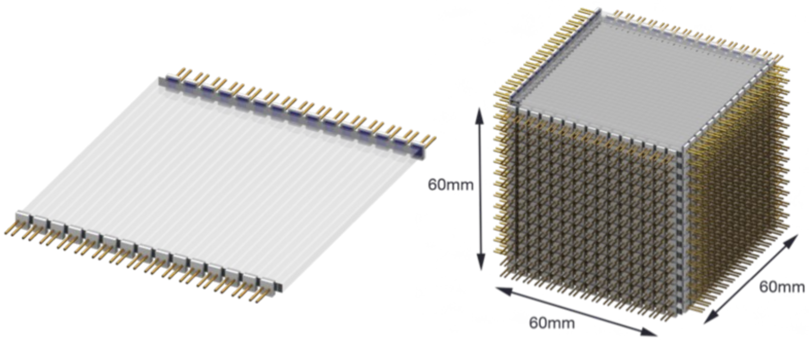
- On-Board Computer
  – ARM Cortex-A5/A7
  – 32+ MB ECC-SRAM
  – 8+MB MRAM
  – I^2C + SPI + generic GPIO

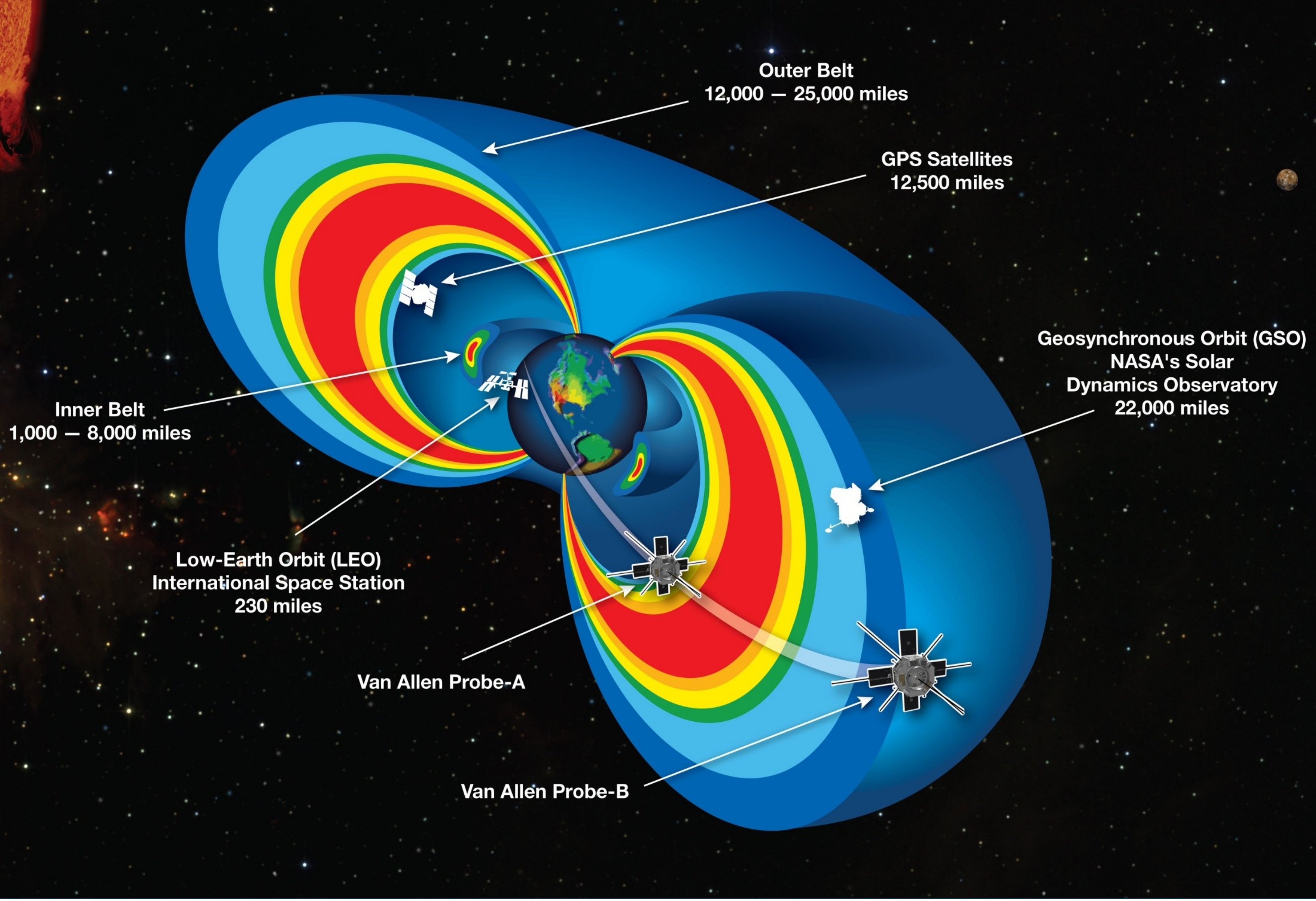
- Dimensions 10 x 10 x 20 cm



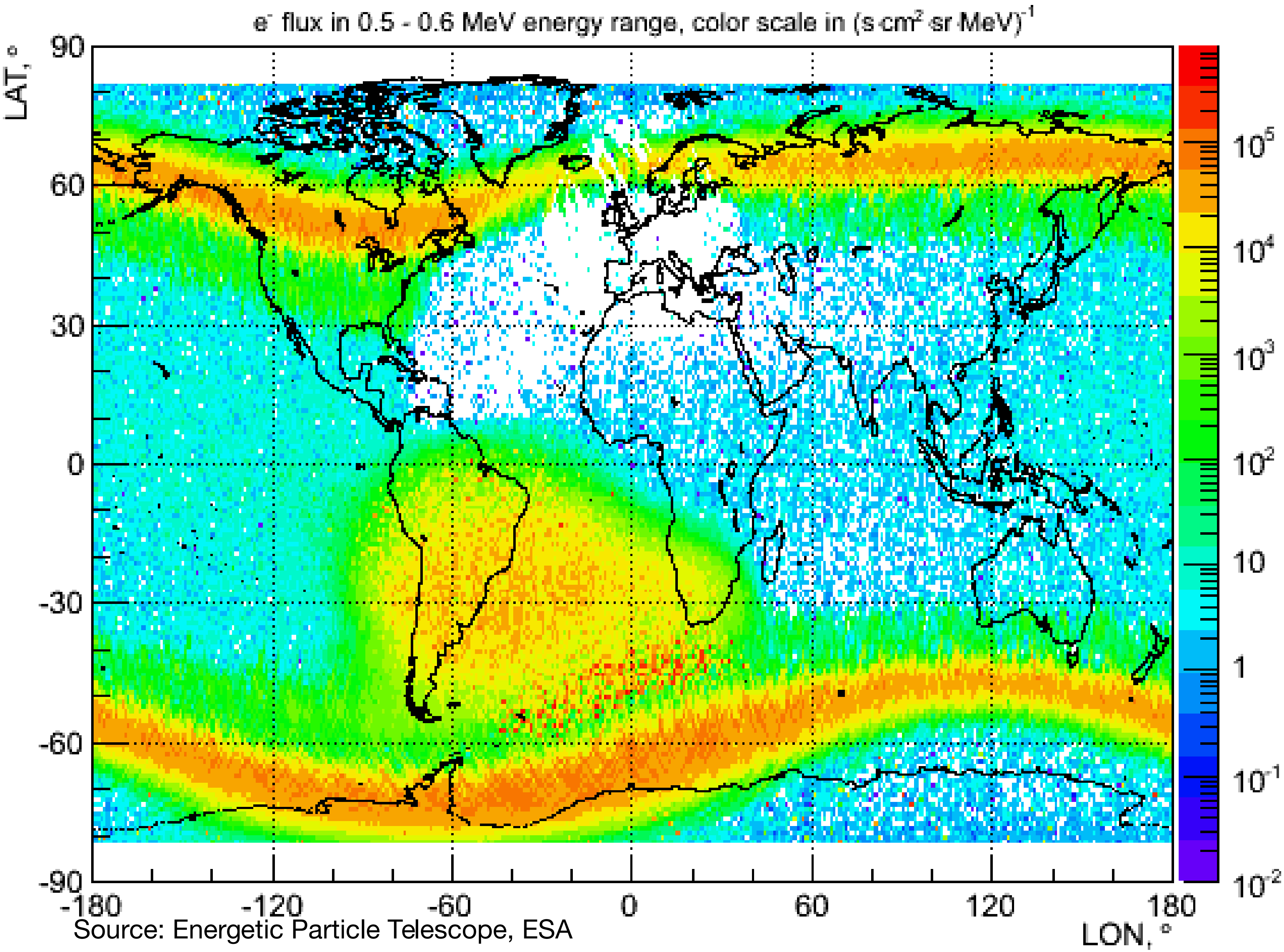
MOVE-II Scientific Payload(s)

- Two Options, decision after PDR:
  - Anti-Prototon Detector
    - High data rate sensor
    - Provided by TUM Department of Physics
  - Foldable Reflector Structure
    - Technology qualification
    - Industrial contribution





Outer Belt
12,000 — 25,000 miles
GPS Satellites
12,500 miles
Geosynchronous Orbit (GSO)
NASA's Solar
Dynamics Observatory
22,000 miles
Inner Belt
1,000 — 8,000 miles
Low-Earth Orbit (LEO)
International Space Station
230 miles
Van Allen Probe-A
Van Allen Probe-B



Source: Energetic Particle Telescope, ESA

Environmental Effects on Electronics in Space

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  - Total ionizing dose, event upsets
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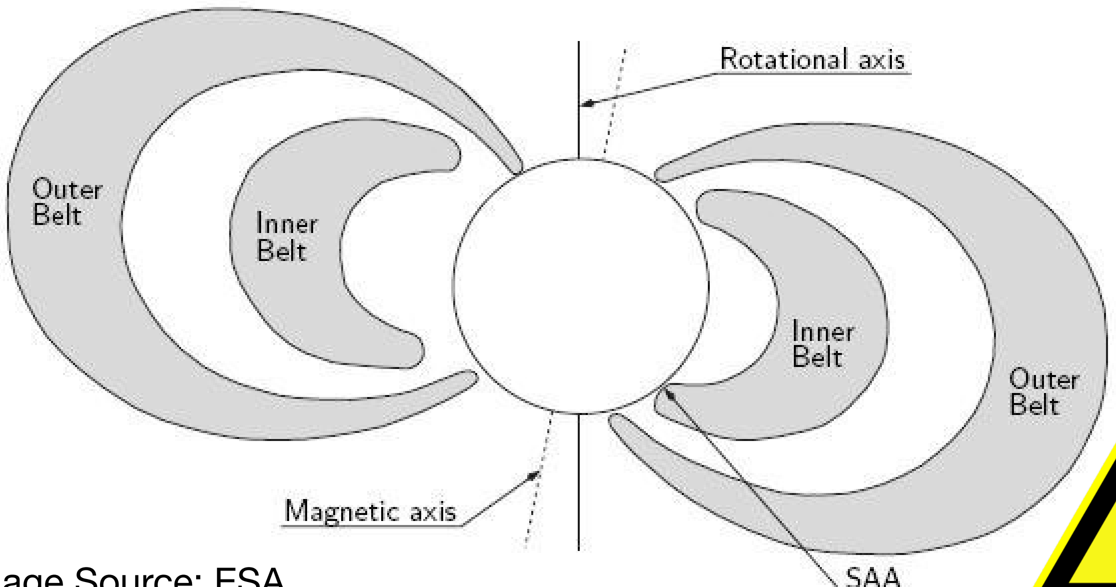
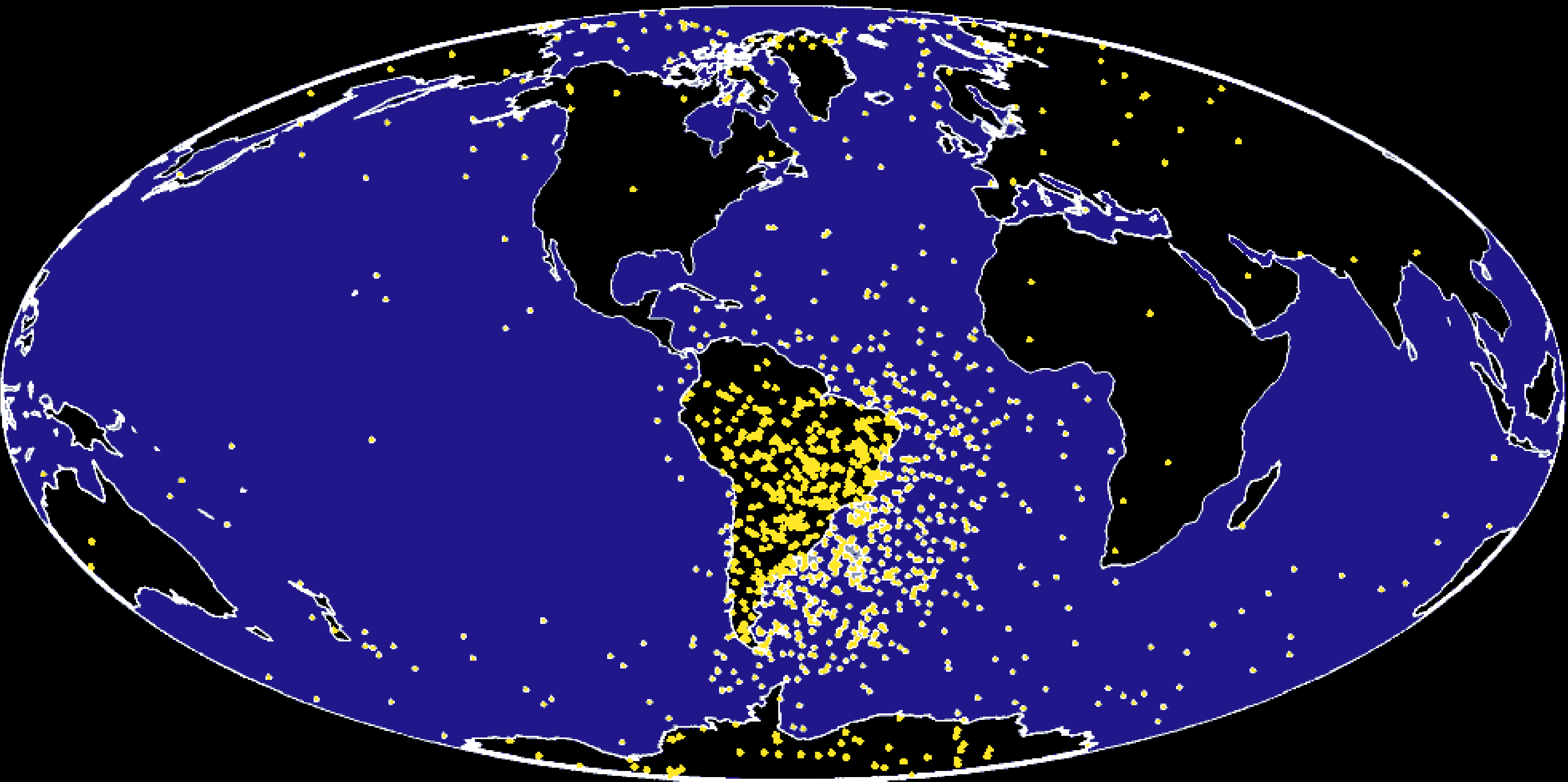


Image Source: ESA

UOSAT-2 Memory Upsets



ESA/ESTEC The Netherlands

NOAA/NGDC Boulder

Memory Integrity

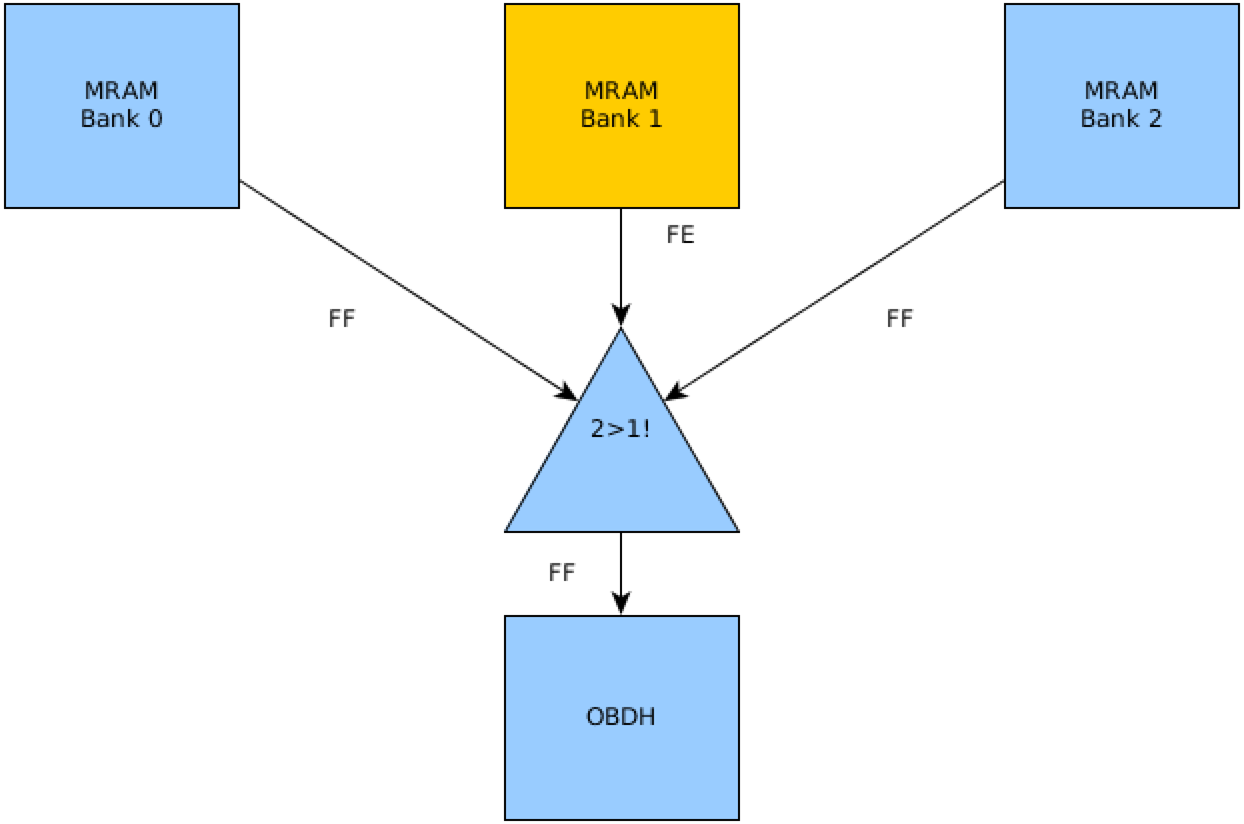
- Core System Storage
  - Kernel, application code, diagnostics
  - Small but consistency is critical
- Payload Data Storage
  - Data storage for scientific data
  - Large – only lossy-technology available (NAND/NOR-flash)
- Volatile Memory
  - Used as system memory
  - Hard and soft faults have equal effect on data
  - Memory checking and blacklisting to handle hard faults

Traditional Approaches for future Hardware?

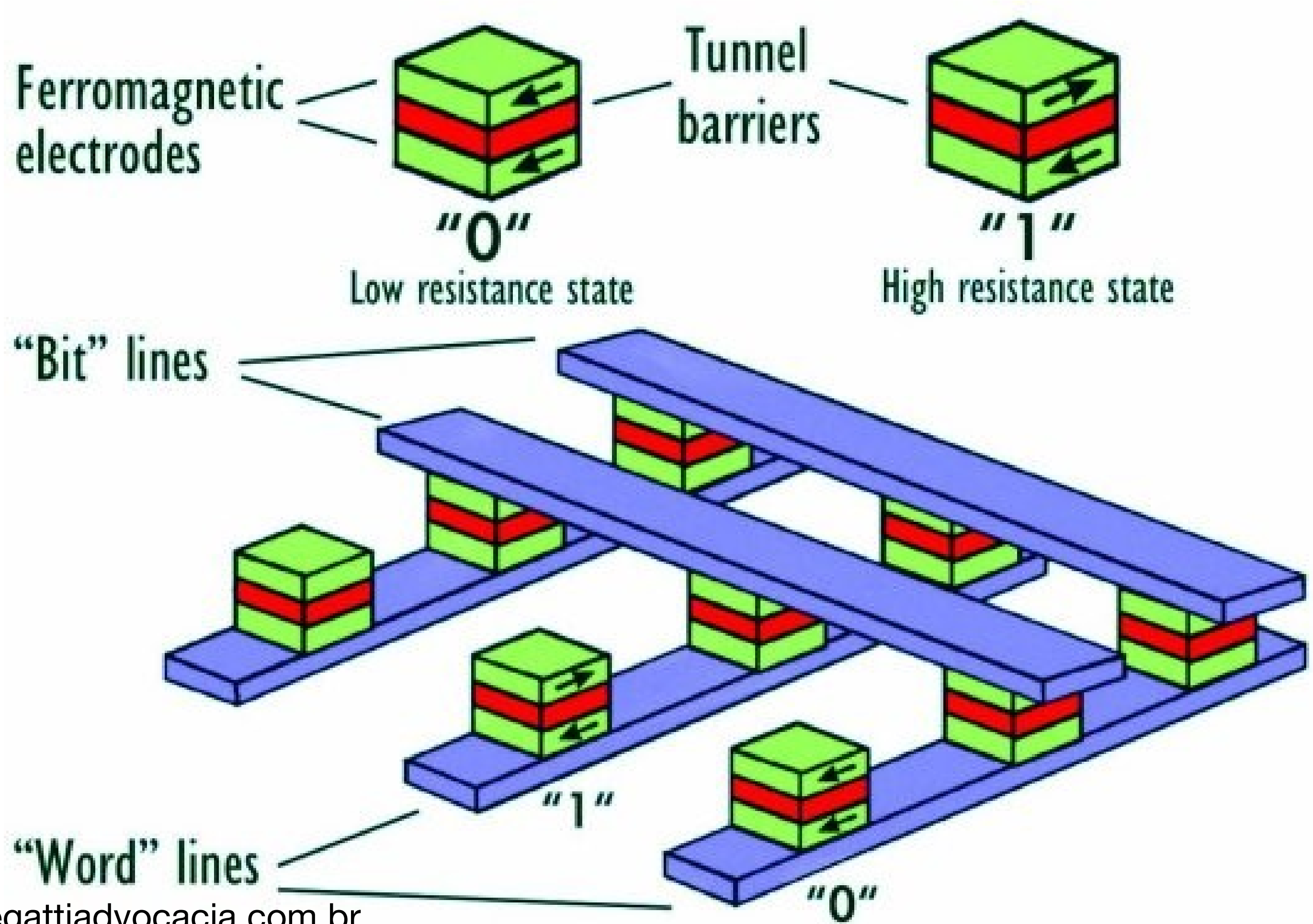
- Coarse structural width
  - Lower impact of event upsets
  - Old parts only -> legacy technology
- Simple redundancy
  - Redundant device's data degrades, even if not in use
  - Consistency & error detection often problematic
  - VERY inefficient and prone to hard-errors
- Hardware Voting
  - Reliance on trusted oracle, byzantine issues
  - Problematic for complex devices (Flash, CPUs, ...)
  - Synchronization issues
- New, more robust manufacturing techniques

Thanks for Listening!

Redundancy via Majority Voting



MRAM



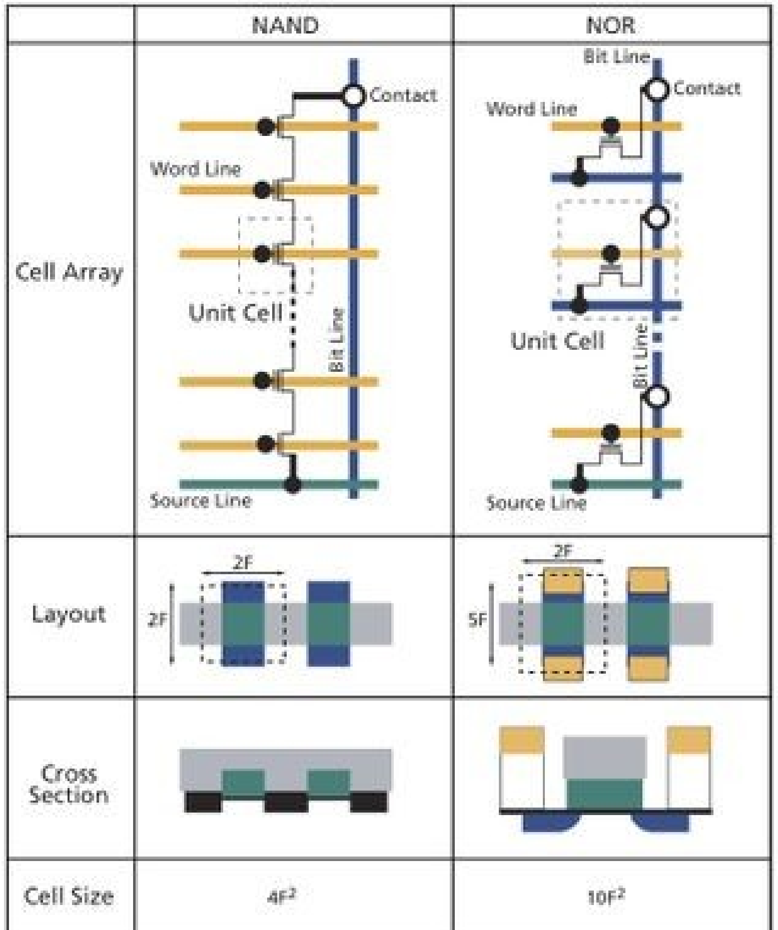
Source: folegattiadvocacia.com.br

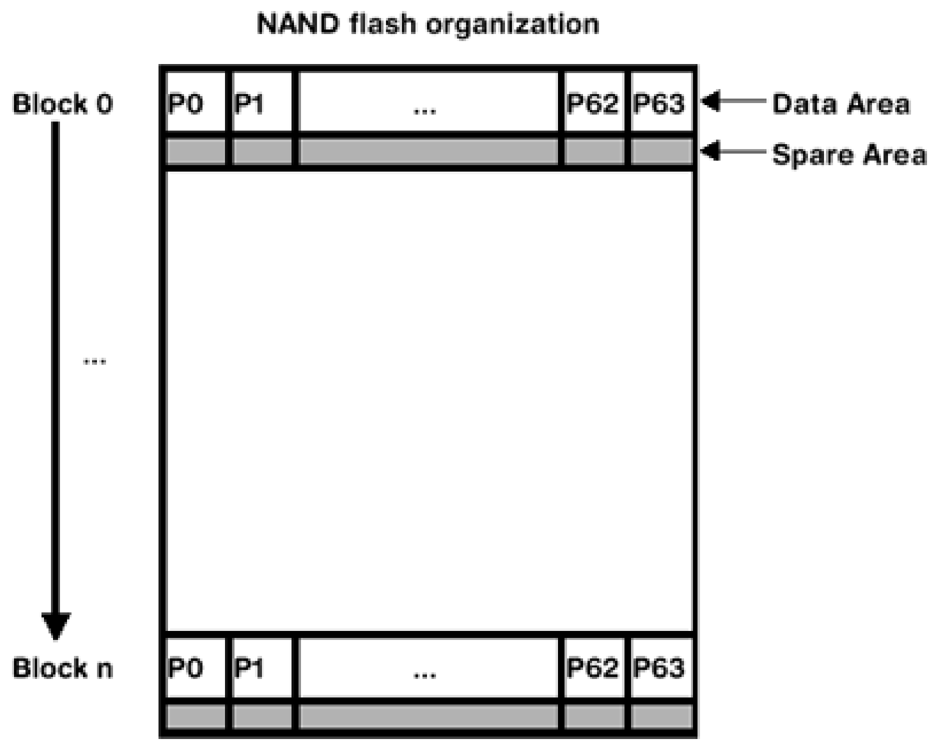
Towards a Large Payload Data Storage

	MRAM	SRAM	DRAM	Flash	FeRam
Read Speed	Fast	Fastest	Medium	Fast	Fast
Write Speed	Fast	Fastest	Medium	Low	Medium
Array Efficiency	Med/High	High	High	Med/Low	Medium
Future Scalability	Good	Good	Limited	Limited	Limited
Cell Density	Med/High	Low	High	Medium	Medium
Non-Volatility	Yes	No	No	Yes	Yes
Endurance	Infinite	Infinite	Infinite	Limited	Limited
Cell Leakage	Low	Low/High	High	Low	Low
Low Voltage	Yes	Yes	Limited	Limited	Limited
Complexity	Medium	Low	Medium	Medium	Medium

Source: www.thefutureofthings.com

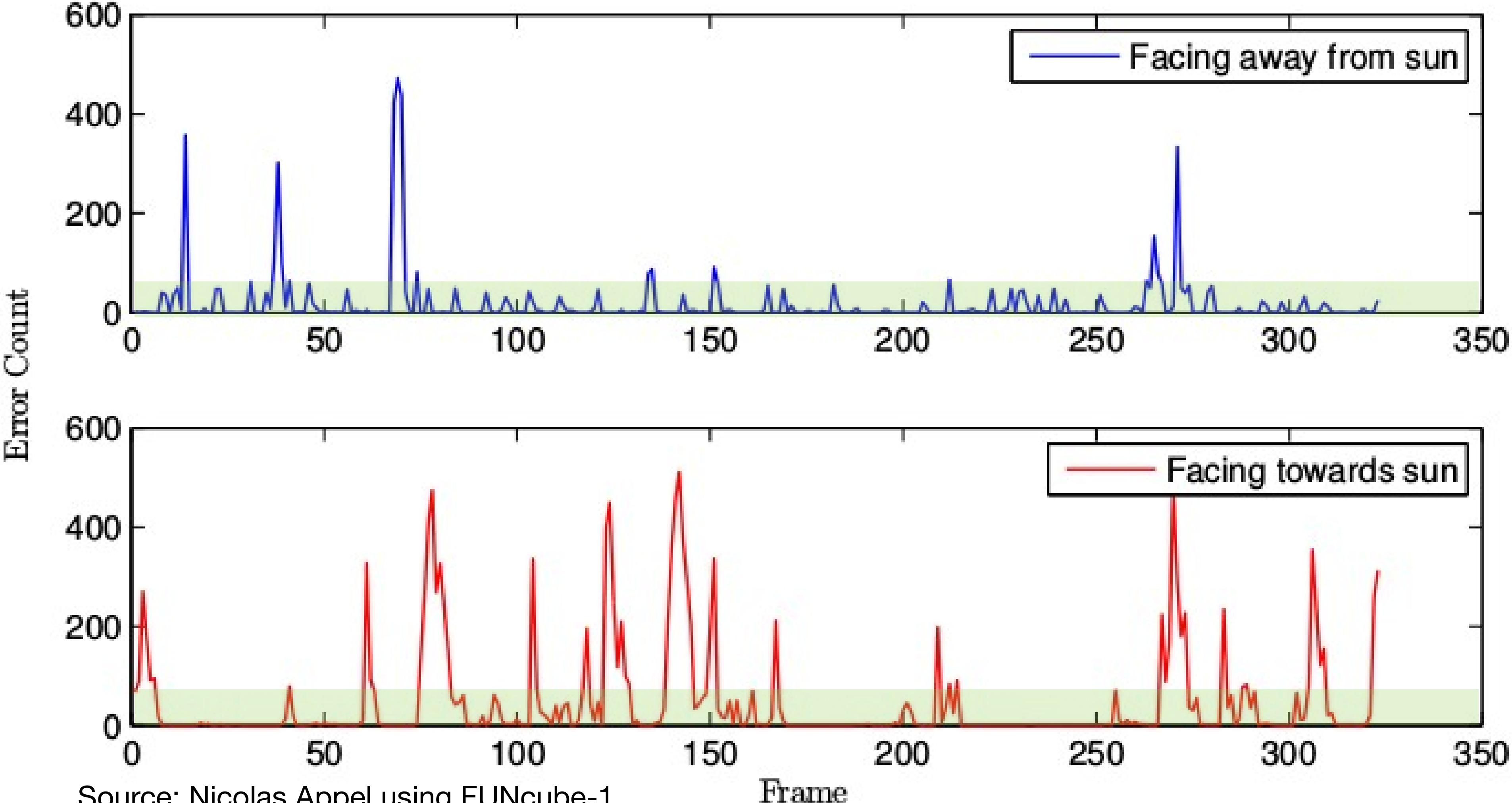
Flash Memory Comparison





Source: Wind River Systems (L), SEGGER Microcontroller (R)

FUNcube-1 Frame Error Rates (VHF)



Source: Nicolas Appel using FUNcube-1 Data